V. Ἀμόρφωτα, No. II.—*On the Epipŏlic Dispersion of Light, being a Supplement to a paper entitled, "On a Case of Superficial Colour presented by a homogeneous liquid internally colourless." By Sir* J. F. W. Herschel, *Bart., K.H., F.R.S., &c.*

Received March 6,—Read April 3, 1845.

In reasoning on the peculiar coloured dispersion operated on a portion of a beam of white light intromitted into a solution of sulphate of quinine, it occurred to me as a subject well worthy of inquiry whether the rays so selected for dispersion and thus singularly separated from the rest, were distinguished by any other peculiarity; whether in effect an *analysis* of the incident light into two distinct species *qualitatively* different had been performed, or merely a simple *subdivision*, such as takes place, for instance, in partial reflexion, as in the phenomena of the colours of thin plates. Another interesting subject of inquiry presents itself in the laws which regulate this singular mode of dispersion itself, which, for brevity, I shall venture to call (at least provisionally) *epipŏlic*, from ἐπιπολὴ, *a surface*, the seat of the dispersion being at or very near the intromitting surface.

As regards the question of analysis, two modes of examination present themselves, viz. either,—1, by subjecting the dispersed portion of the light to experiment, or, 2, the residual portion, which, having escaped dispersion, preserves the unity of its direction; and on that account, as well as by reason of its vastly superior intensity, offers itself more readily to experimental inquiry.

The colour of the dispersed portion being blue, that of the residual beam ought, of course, to verge towards orange. But owing to the large excess of undecomposed white light present, this tendency is inappreciable; and the regularly transmitted beam is not to be distinguished by the eye from white light. Another reason is, that some portion of the dispersed necessarily mingles with the regularly transmitted beam, the medium being equally *permeable* to both; so that in viewing an extensive white surface (the cloudy sky for instance, or a piece of white paper), the regularly transmitted ray reaching the eye in any given direction, that is, from any one point in the luminous surface, has, intermingled with it, a dispersed ray from every other point of that surface, the totality of which goes to restore to it some material portion of the blue light which it lost by dispersion at its intromission.

In the ordinary production of colour in liquids by absorption of the complementary tint, the smallest preference of one over the other coloured rays may be magnified and brought into evidence as a cause of coloration by increasing the thickness of the transmitting medium, or by passing the light successively through

many vessels filled with it. Accordingly it might be supposed that by passing the same incident beam successively through many such dispersive surfaces, the whole of the blue rays would at length be separated from it, and an orange, or red residual beam be left. But this is not the case, the reason of which is to be found in a very remarkable peculiarity in the transmitted light, which may be thus announced.

An epipolized beam of light (meaning thereby a beam which has been once transmitted through a quiniferous solution and undergone its dispersing action) *is incapable of further undergoing epipolic dispersion.*

In proof of this, the following experiments may be adduced.

Exp. 1. A glass jar being filled with a quiniferous solution*, a piece of plate-glass was immersed in it vertically, so as to be entirely covered and to present one face directly to the incident light. In this situation, when viewed by an eye almost perpendicularly over it, so as to graze either surface very obliquely, neither the anterior nor posterior face showed the slightest trace of epipolic colour. Now the light, at its egress from the immersed glass, entered the liquid under precisely the same circumstances as that which, when traversing the anterior surface of the glass jar, underwent epipolic dispersion on first entering the liquid. It had therefore lost a property which it originally possessed, and could not therefore be considered, *qualitatively*, the same light.

Exp. 2. The epipolic tint is developed only on the surface of incidence. When the solution is exposed to light in a glass vessel, the posterior surface, whether viewed internally or externally, is quite colourless. Here again, since ingress and egress into and out of a medium are, optically speaking, convertible, *a qualitative analysis* at the surface of incidence would appear to be indicated.

Exp. 3. A test cylinder filled to the height of two or three inches with the solution was set upright on black velvet, its bottom being also shaded to the depth of half an inch (to prevent reflected light from the bottom from reaching the eye). The epipolic tint being now fully developed, a hollow parallelopiped of plate glass, filled with the same solution, was interposed between the test cylinder and the incident light, side light being at the same time obstructed by screens duly placed. Immediately the epipolic colour in the interior of the cylinder vanished altogether. The transmitting vessel was now emptied of its contents and filled with pure water,

* The solution here used and subsequently referred to (except when otherwise expressed) is formed by adding to sulphuric acid, diluted to such an extent as just to bear being swallowed without pain, about one two-hundredth part of its weight, (the weight, i. e. of the *diluted* acid) of sulphate of quinine. When of this strength it is difficult to believe that a bottle half-filled with it contains a colourless liquid. When shaken, it tinges the glass vividly blue: lively blue gleams are reflected from the interior, and from the capillary ring at the surface level, &c. I may mention that in one instance a rose-coloured solution was formed, which I have never been able to reproduce. The ingredients were taken from the very same parcels which gave the usual colourless solution, and the mixture made in the identical vessel which had just recently served for the same experiments, and which had not even been washed, and from which a colourless solution had just been emptied. If owing to any foreign ingredient accidentally present, the quantity must have been inconceivably minute.

from which its former contents were in no way distinguishable by an eye situated behind it. Being then replaced as before, so as to intercept the light incident on the test cylinder, the epipolic colour was produced, exactly as if nothing had been interposed; a trifling difference of intensity only excepted, which arose from the glass used not being wholly devoid of colour.

Exp. 4. This experiment was varied so as to present a result disengaged from this slight source of uncertainty, and perfectly decisive. A cylindrical jar was coated externally with black paper round three-fourths of its circumference, as was also its bottom, and a ring of the same paper was carried round the cylinder at the bottom so as to cut off light from being internally reflected on its base. In it was set upright a test cylinder of the solution, and the jar was then filled with pure water rising considerably above the solution in the cylinder. When exposed to light as usual, the epipolic tint was finely seen. But on emptying out the water, and introducing in its stead an equal quantity of the quiniferous solution, the tint in question was completely destroyed, whether the surface of the cylinder was viewed from within or from without, proving evidently that no rays susceptible of epipolic dispersion had reached its surface. This result was rendered the more remarkable by an effect of contrast. The *external, upper* portion of the cylinder, above its liquid contents, but below the level of the liquid in the jar, reflected to the eye (or rather the air within it reflected) a pretty strong blue gleam, being no other than the epipolically dispersed light of the anterior surface of the liquid in the jar; while all below (being glass in contact with the liquid on both sides and so deprived of reflective power on both surfaces) was completely dark and almost invisible.

When the interior test cylinder was sloped backwards from the incident light at an angle of about 70° to the horizon, a beautiful and instructive feature was developed. In this situation of things, the interior liquid being as usual the quinine solution, and the exterior pure water; to an eye perpendicularly over the surface, the whole anterior portion of the cylinder from below upwards to the surface of the interior liquid, appeared coated as it were internally with a most delicate and beautiful blue film of extreme tenuity and perfect transparency, presenting a singular ghost-like appearance, easier produced than described. This being seen *through* the cylinder, by an eye situated externally to its prolongation, affords a proof that the epipolic dispersion takes place in all directions: but except in this mode of viewing it the rays dispersed outwards cannot reach the eye, or not in abundance (for which a very oblique incidence is required), being at such an incidence internally and totally reflected by the outer surface of the glass. To see this to advantage an eye-tube internally blackened should be used to guard the eye from extraneous light. Such a tube indeed is generally advantageous in all these experiments.

If, instead of water, the test cylinder be plunged into a solution of quinine, all else remaining as before, the blue film in question *totally disappears*. I tried a great many other liquids, all in fact which I had at hand in sufficient quantity and colour-

less, or but little coloured, in hopes of discovering something which might elucidate the subject. Strong alcohol, solution of corrosive sublimate, ammonia, &c. acted as water; allowing the blue film to be seen externally at a perpendicular incidence of the visual ray to the surface of the liquid. With strong sulphuric acid, and with muriate of lime so concentrated as to be syrupy, this was not possible, but the film became visible, and of its full intensity, on moving the eye forward (i. e. towards the incident light). When sulphate of manganese was used, its delicate pale rose-colour no way prevented a fine exhibition of the blue film (a point to which I shall have occasion to revert). On the other hand, the lemon yellow-colour of nitrate of uranium (a much fuller tint) materially enfeebled, though it did not prevent the formation of the film. This last effect did however appear to be produced by two liquids, viz. pyroxylic spirit in a small degree, and oil of turpentine in a much greater; the effect in this case being very obviously much more than could justly be attributed to a trifling tinge of yellow in the oil (which was not fresh), as I satisfied myself by a comparative experiment with water purposely coloured to a similar tint of greater intensity. Neither of these liquids however was found on trial in the test cylinder, or otherwise, to possess in the smallest degree the property of epipolic dispersion; nor have I found any other liquid which does so.

Exp. 5. Among solids the only one I am acquainted with possessed of a similar property, is the green fluor of Alston Moor, which exhibits by superficial dispersion a fine deep blue colour, very different from the inherent or absorptive colour of the mineral. This is strictly an epipolic tint, as the following experiment will show, and at the same time affords another, and not a little striking confirmation of the general proposition announced in p. 148. I should premise that to see the epipolic colour of the fluor in perfection, it must be laid on black velvet, or the reflexion of light from its posterior surfaces must be destroyed by roughening and coating them with black sealing-wax. In this state, if exposed to daylight at a window, and viewed through a blackened eye-tube, it is seen not as a green, but as a fine deep blue crystal.

If a piece of fluor so prepared be placed in water in a glass standing on black velvet, the blue epipolic colour is seen greatly heightened. But if the water be exchanged for a solution of quinine, this colour is completely destroyed and the surface appears simply black. To make the experiment successfully, the greatest care must be taken to cut off all lateral or reflected light. The arrangement I adopted was, to coat a fluor as above described, and fastening it with black sealing-wax to a wire, to lower it into the coated jar described in Exp. 4, filled alternately with a solution of quinine and with pure water. Using the eye-tube for further precaution, the destruction of the epipolic tint by the solution was quite as complete as if instead of the fluor a test glass full of the quiniferous solution had been used.

It would certainly appear from these experiments that the residual beam after undergoing epipolic dispersion had lost some constituent portion, or otherwise under-

gone some qualitative modification which might be considered as rendering it specifically different from the incident beam. It cannot be the mere tinge of *colour* which the loss of so small a portion of blue light has given to it. There is still plenty of blue light left, and the experiment on sulphate of manganese proves that a mere *absorption* of a much larger proportion of the blue rays has not the same effect. Moreover the portion of light *dispersed* traverses the solution of quinine with perfect facility, proving that no peculiar absorptive power *is* exercised by that medium on these rays; nor indeed would the separation of such rays by dispersion at the surface in any way tinge *the medium itself* with a complementary tint, but only the residual beam.

I come now to the examination of the dispersed portion of the light. As just remarked, when once *dispersed* it is *freely transmitted.* The epipolic colour is seen as well, in a long test-cylinder filled with the solution, at the bottom of the tube as at the top, when viewed by an eye situated in its axis, supposed vertical. If all light be cut off from the tube by a sheet of black paper rolled round it, except from the lowest inch of its length, that inch is seen to gleam with quite as intense a colour as when the uppermost inch only is so exposed.

I have already had occasion to remark that the epipolic tint is a compound one. To obtain a pure ray for prismatic analysis, a cylindrical glass jar with perpendicular sides was partly filled with the quiniferous liquid and placed in a strong light, the whole anterior side being coated with black paper rising somewhat above the level of the liquid. The eye was then placed in such a position, below that level, that the visual ray proceeding *from* it would suffer total reflexion at the under surface. For comparison, a similar vessel of water, similarly shaded, was placed beside it. The surface of this, so viewed from below, was of course perfectly black, no ray from above being able so to penetrate it as to reach the eye. Not so the quiniferous solution. In this the under surface was wholly visible, of a fine blue colour, considerably deeper in tint than in the ordinary mode of viewing it, though not of so rich and saturated a character as the epipolic blue of the fluor. It was, however, much more luminous, and being thus completely purified from all possible admixture of regularly refracted or reflected light, was well-adapted for prismatic analysis.

By raising the eye exactly to the horizontal level of the surface of the liquid, the whole of that surface became of course foreshortened into a narrow blue line. And in this situation it became perfectly evident that this line was not a mere elongated ellipse, the perspective representation of the circular area of the surface, but a very narrow parallelogram, having a breadth of about a fiftieth of an inch, of a vivid and nearly uniform blue colour over its whole breadth. This proves that the epipolic dispersion takes place *within* the liquid, and almost wholly within a distance not exceeding one-fiftieth of an inch from the surface. I say *almost* wholly; for when a sunbeam was directed downwards on the surface, by total reflexion from the base of a prism, a feeble blue gleam was observed to extend downwards below this vivid

line to nearly half an inch from the surface, thus leaving it doubtful whether some small amount of dispersion may not be effected in the interior of the medium at appreciable depths.

The narrow blue line above described was viewed through a Fraunhofer flint prism. The spectrum was deficient at the red end by the totality of the purer and less refrangible red, nearly the whole orange, and all the yellow. A rich and broad band of fine green light slightly fringed with red on the less refrangible side, passed suddenly, on the more refrangible, to a copious indigo and violet without any intermediately graduating blue. Either from want of sufficient brightness, or from some other cause, no black lines were seen; as far as mere illumination went, the spectrum developed appeared continuous.

It appears from this that no one prismatic ray in particular is selected for epipolic dispersion, but that a certain small per-centage of rays extending over a great range of refrangibility are subject to be so affected, the less refrangible extreme being however wholly excluded, as well as the majority of all below a mean refrangibility.

The epipolic colour is more intense the more oblique the visual ray is to the dispersing surface. This, which would be inexplicable on the supposition of the dispersion being effected rigorously at the *geometrical* surface of the medium, is a necessary consequence of its taking place within a superficial stratum of very small, but appreciable thickness, or according to a law of intensity decreasing with great rapidity as the depth within the medium increases. It has been already shown that the dispersion is not confined to the interior of the liquid, but that a large portion of the dispersed light is directed *outwards*, Exp. 4. The more oblique portions of this (which are also the more intense) require, as is there shown, peculiar management to render them visible. Those whose inclination to the dispersive surface is greater, may also be subjected to ocular inspection, by carefully destroying all regularly reflected or accidental light. Thus, if on a surface of black paper two blots be made, the one of water, the other of a solution of quinine, and if these be laid before a window and viewed through a blackened tube in any direction but that of regular reflexion, the water will appear perfectly black, the quinine feebly blue. But however oblique to the surface the visual ray may be in this case, no great accession of intensity takes place in the epipolic tint, for this obvious reason, *that* the dispersing stratum being *within* the medium, no ray dispersed by it can penetrate the surface, which has not an inclination thereto exceeding 41° 22′, at which angle, therefore, it must cut the stratum, and cannot therefore traverse any great extent of it bodily.

Hence, moreover, on the other hand, the internally dispersed light, at great obliquities to the surface (supposed in contact with air), will be reinforced by all that portion which would have penetrated the surface and gone into the air but for the law of total reflexion; all the dispersed rays, that is to say, whose inclination to the surface is less than 41° 22′. This consideration helps to explain the great comparative intensity which the dispersed beam possesses under such circumstances.

As it has been clearly shown that a beam of white light from which certain rays have been separated by epipolic dispersion is no longer susceptible of producing the epipolic phenomena, it would seem a natural and almost a necessary conclusion, that the rays so separated ought to be *wholly*, or in a very high degree, so dispersed when incident on an epipolizing surface. But the whole history of physical optics is one continued warning against such seeming logical conclusions; and in this case also the conclusion is not borne out by fact. Thus in Exp. 2 and 4, abundance of rays internally dispersed must of necessity have been incident on the new surface presented to them, yet no fresh dispersion whatever took place. I may add too that in experiments made with considerable care to exclude all other light from incidence on a quiniferous surface, but such as had originated in epipolic dispersion, I have not succeeded in obtaining any indication of their susceptibility of being a second time so dispersed. Though from the obscurity of such rays as compared with direct light, these trials can hardly be considered as proving a negative, yet they certainly go very far towards proving the absence of any *peculiar* susceptibility in those rays to this particular affection.

J. F. W. HERSCHEL.

Collingwood, March 1, 1845.

Note added during the Printing.—Professor GRAHAM has had the kindness to transmit to me a specimen of an alkaloid, extracted from the brown coat of the seed of the chestnut, to which the name *Esculine* has been given, which possesses in perfection the property of epipolic dispersion when in dilute solution, in which state it precisely resembles quinine. The same eminent chemist refers also to a peculiar oil called Colophene, formed by the regulated action of sulphuric acid on oil of turpentine, which by his description of its phenomena, must also be an epipolizing liquid of a similar character.

J. F. W. H.

May 12, 1845.